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Tsuji et al.

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[54] COMPOSITE PRISM AND OPTICAL PICKUP USING THE SAME

[75] Inventors: Hiroyasu Tsuji, Sennai-gun; Toshio Fukuzawa, Kyoto; Shogo Nasu, Kobe; Norimoto Nochi, Katano; Shinji Uchida; Tsuguhiro Korenaga, both of Neyagawa, all of Japan

[73] Assignee: Matsushita Electric Industrial Co., Ltd., Japan

[21] Appl. No.: 08/968,587

[22] Filed: Nov. 13, 1997

[30] Foreign Application Priority Data

Nov. 13, 1996 [JP] Japan 8-301544

[51] Int. Cl.^{6} G11B 7/00

[52] U.S. Cl. 369/112; 369/103; 369/109

[58] Field of Search 369/100, 109, 369/110, 112, 44.23, 44.24, 103

[56] References Cited

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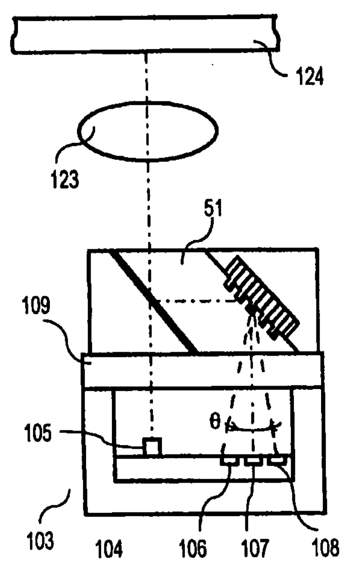
Primary Examiner—Paul W. Huber
Attorney, Agent, or Firm—Parkhurst & Wendel, L.L.P.

[57] ABSTRACT

A prism and an optical pickup employing such prism includes a parallel prism having a polarization beam splitter film and a reflection film. The polarization beam splitter film is formed on an angled plane of a glass material having an approximate parallelogram cross-section, and consists of a multi-layer film of a composite film made of Si and SiO_{2-x} ($x<0.5$) and multiple layers of multiple dielectric films. The reflection film is formed on an angled plane of the same glass material approximately parallel to the angled plane on which the polarization beam splitter film is formed, and consists of a multi-layer film of a composite film made of metal Si and oxide SiO_{2-x} ($x<0.5$) as a high refractive film and multiple layers of multiple dielectric films as a relatively low refractive film.

23 Claims, 15 Drawing Sheets



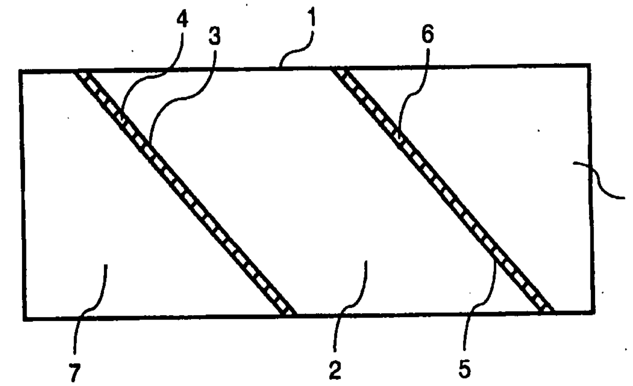
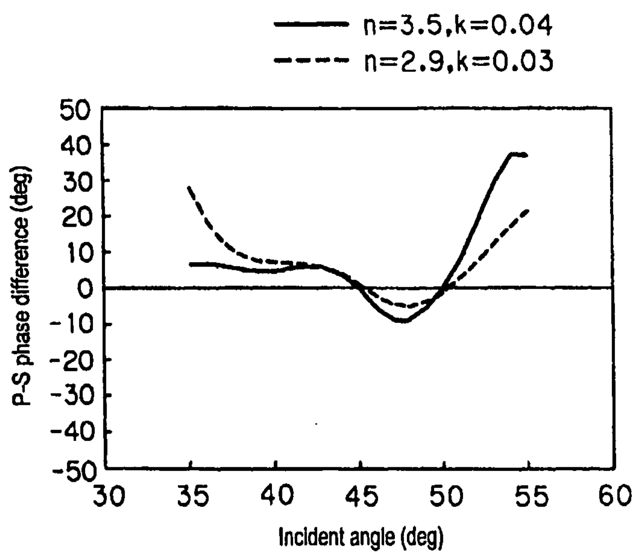


FIG. 1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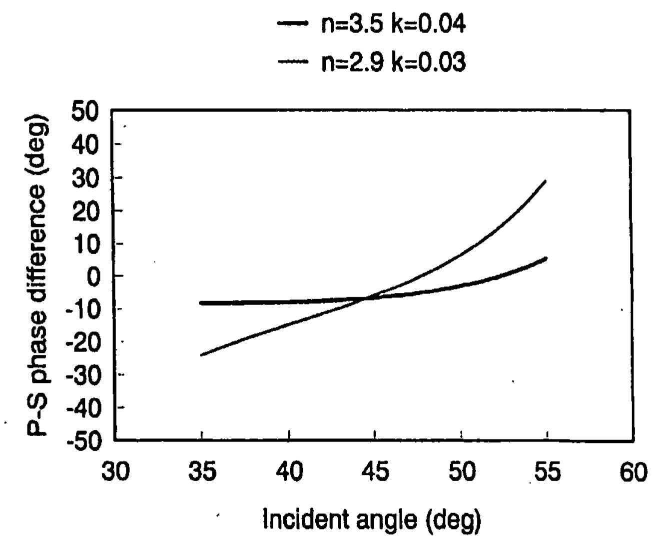
n=2.9,k=0.03
P-S phase difference (deg)
50
40
30
20
10
0
-10
-20
-30
-40
-50
30
35
40
45
50
55
60
Incident angle (deg)

FIG. 2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n=2.9 k=0.03
P-S phase difference (deg)
50
40
30
20
10
0
-10
-20
-30
-40
-50
30
35
40
45
50
55
60
Incident angle (deg)

FIG. 3

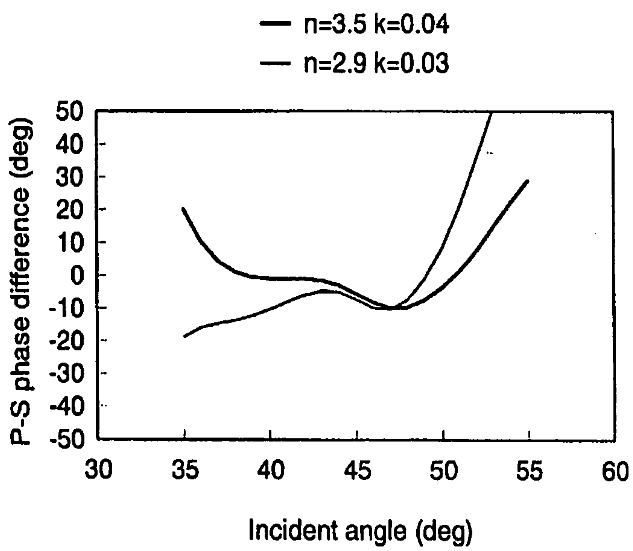
n=3.5 k=0.04
n=2.9 k=0.03
P-S phase difference (deg)
50
40
30
20
10
0
-10
-20
-30
-40
-50
30
35
40
45
50
55
60
Incident angle (deg)

FIG. 4

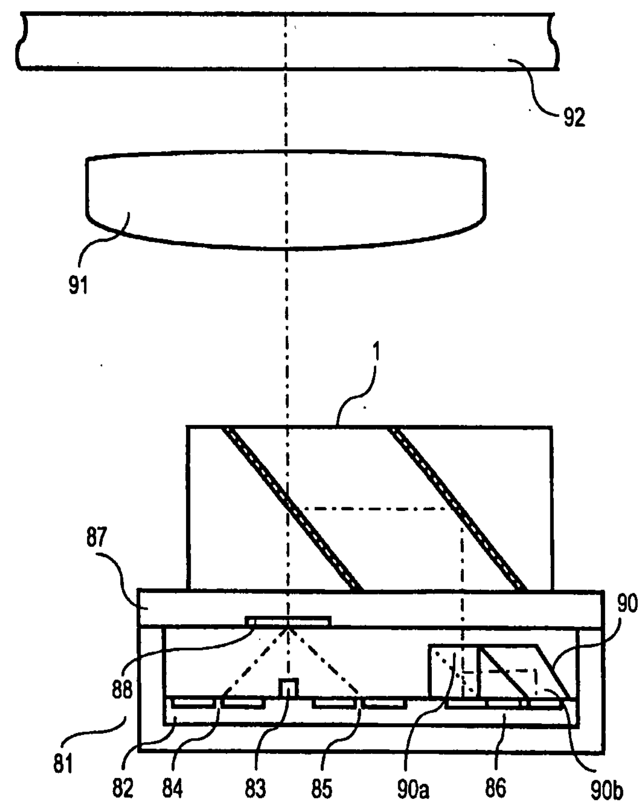
92
91
1
87
90
88
81
82
84
83
85
90a
86
90b

FIG. 5

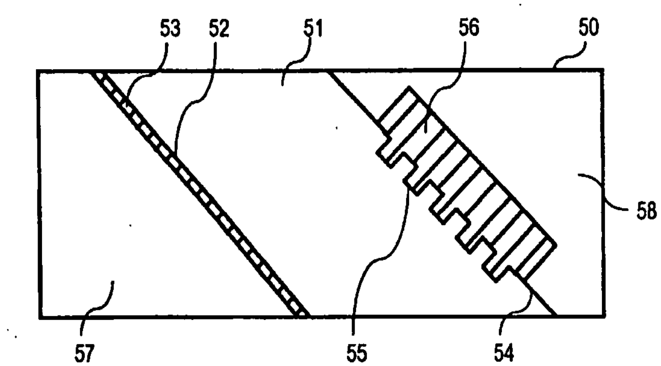
53
52
51
56
50
58
57
55
54

FIG. 6

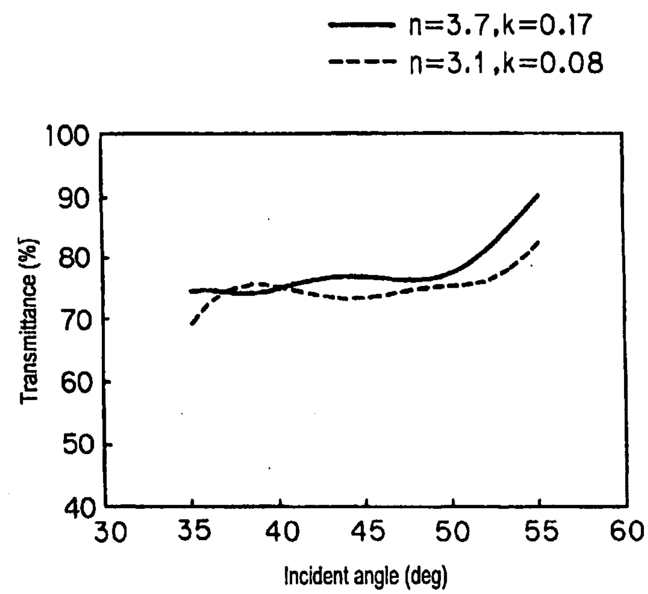
n=3.7,k=0.17
n=3.1,k=0.08
Transmittance (%)
100
90
80
70
60
50
40
30
35
40
45
50
55
60
Incident angle (deg)

FIG. 7

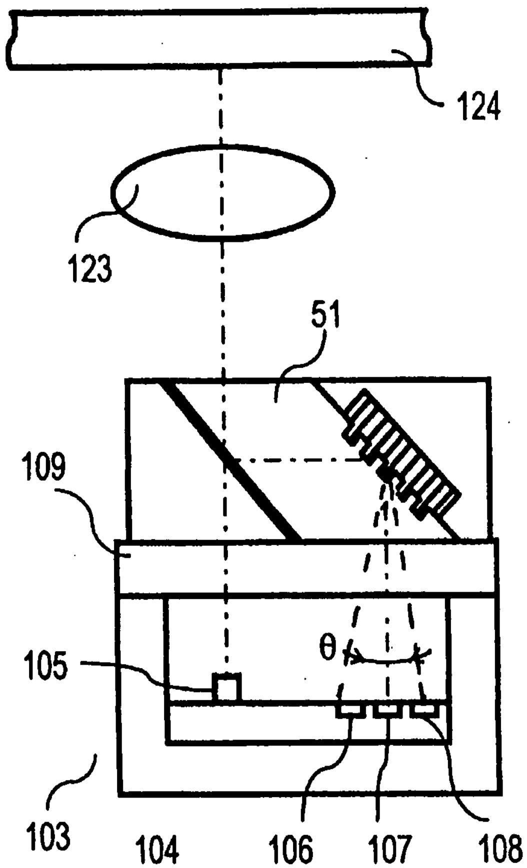

FIG. 8

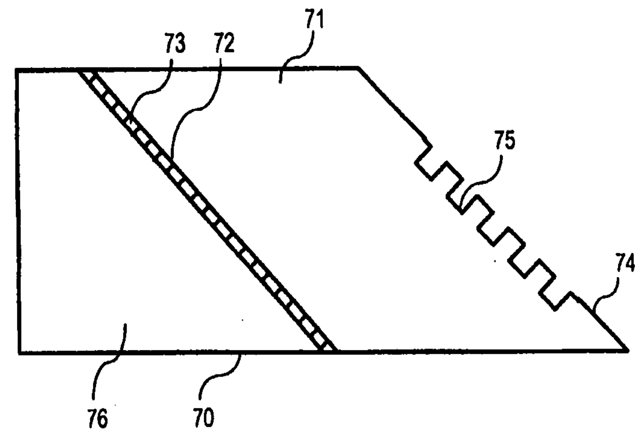

FIG. 9

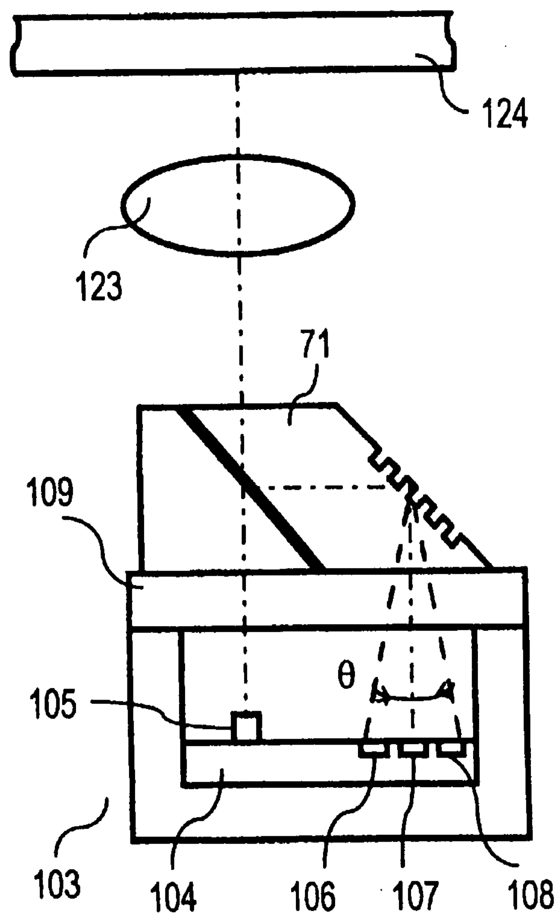

FIG. 10

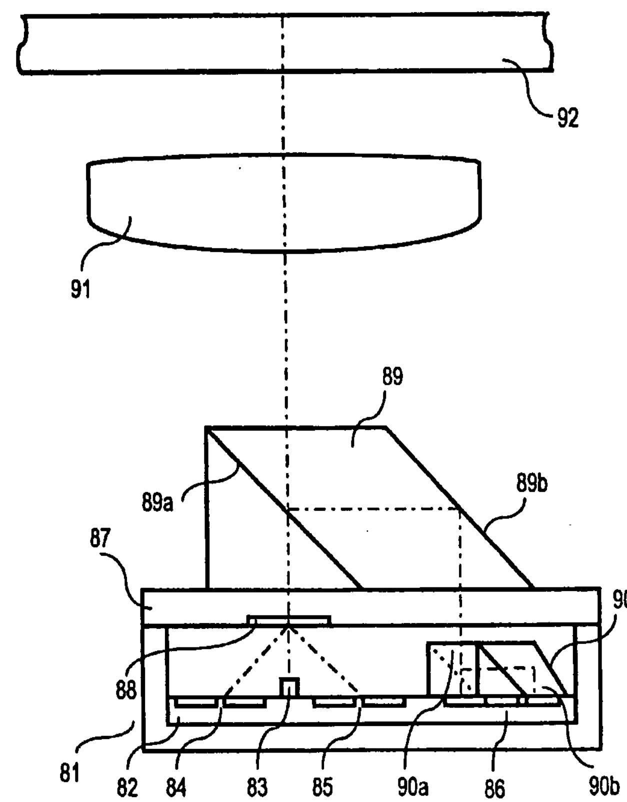

FIG. 11A
PRIOR ART

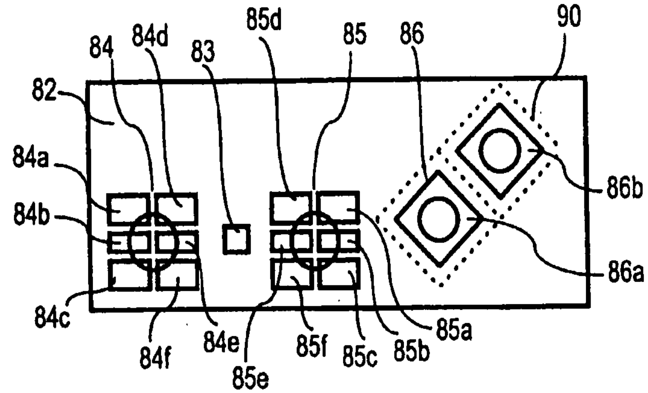

FIG. 11B
PRIOR ART

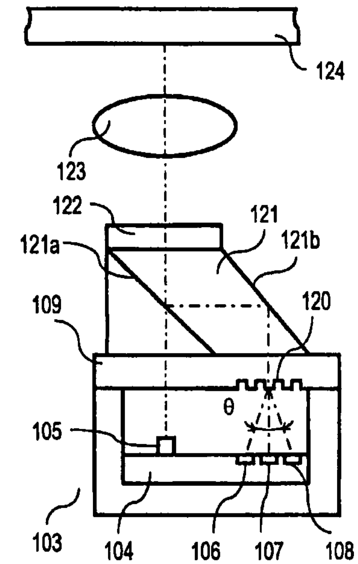

FIG. 12A PRIOR ART

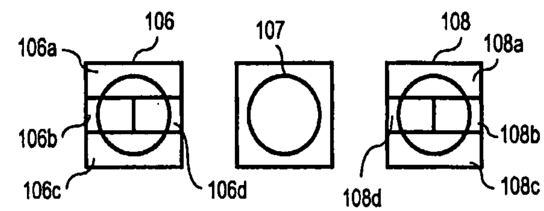

FIG. 12B PRIOR ART

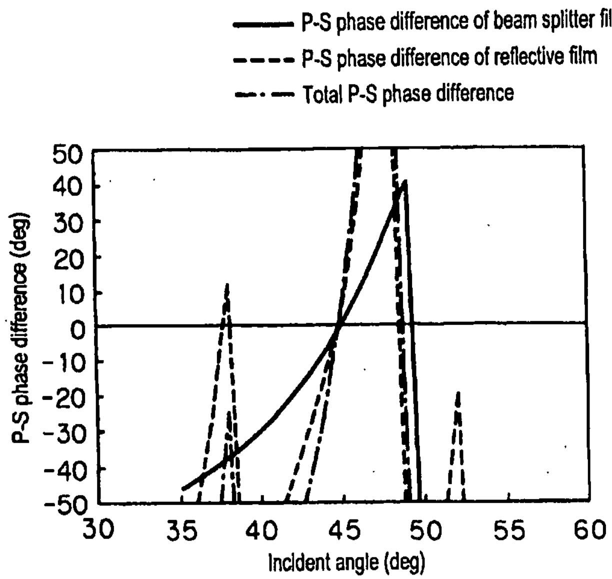

FIG. 13 PRIOR ART

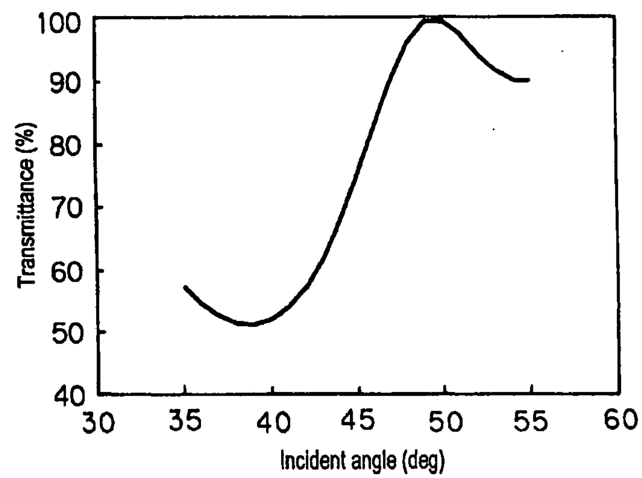

FIG. 14 PRIOR ART

COMPOSITE PRISM AND OPTICAL PICKUP USING THE SAME

FIELD OF THE INVENTION

The present invention relates to the field of prisms, and optical pickups employing prisms for integrating diffused light.

BACKGROUND OF THE INVENTION

At present, magneto-optical disks, write-once optical disks, and compact disks (CDs) are already commercialized as optical disks for recording and reproducing information via irradiation of laser beams. There is, however, increasing interest in digital video disks (DVDs) as the next generation recording medium.

An optical pickup is a device for recording and reproducing information to and from optical disks. Increasing importance is now being placed on development of technology for miniaturization of optical pickups in response to the increasing trend towards integration.

One example of an optical pickup is Japanese Patent Application H7-136462 which discloses a small optical pickup for magneto-optical disks shown in FIGS. 11A and 11B. FIG. 11A is a simplified sectional view of an optical system of the above prior art. FIG. 11B is a top view of a light receiving element, light emitting element, and analyzer. In FIGS. 11A and 11B, a substrate 82 is provided inside an optical module 81. A laser diode 83 as the light emitting element and photo detectors 84, 85, and 86 as the light receiving element are disposed on the substrate 82. The laser diode 83 has a structure which allows, for example, a concave portion having a 45° angled plane (not illustrated) to be disposed on one part of the substrate 82, and a light emitting chip (not illustrated) to be disposed inside that concave portion for reflecting light radiated from the light emitting chip on the 45° angled plane, thus routing the beam upward. Each of the photo detectors 84 and 85 consists of six components: 84a to 84f and 85a to 85f, respectively. The photo analyzer 86 consists of two components: 86a and 86b which are inclined approximately 45° with respect to the array direction of the photo detectors 84 and 85.

The transparent substrate 87 is made of glass or resin, and has a hologram diffraction grating 88 on the side facing the laser diode 83. The hologram diffraction grating 88 has a lens effect, giving different focal lengths to ± primary diffraction light which have been diffracted between approximately 5° and 20°. The transparent substrate 87 is provided over the optical module 81 to seal the inside of the optical module 81. A polarizing prism 89 has a trapezoidal cross-section, formed by bonding a triangular prism having a right triangle cross-section and an approximate parallel prism having an approximate 45° cross section. A polarization beam splitter film consisting of multiple layers of a range of thin dielectric films as shown in Table 1 is applied to a bonded portion 89a of the crystal polarizer 89 in such a way, for example, that the transmittance of p-polarized light is approximately 70%, the reflectance of p-polarized light is approximately 30%, and the reflectance of s-polarized light is approximately 100% when p-polarized light is emitted from the laser diode 83.

TABLE 1

		Film thickness
Substrate	n = 1.635	—
1st layer	TiO_2	119 nm
2nd layer	SiO_2	183 nm
3rd layer	TiO_2	119 nm
4th layer	SiO_2	183 nm
5th layer	TiO_2	119 nm
6th layer	SiO_2	183 nm
7th layer	TiO_2	119 nm
8th layer	SiO_2	183 nm
9th layer	TiO_2	119 nm
Substrate	n = 1.635	—

The polarizing prism 89 is integrated onto the transparent substrate 87, and an angled plane 89b inclines toward the inside of the optical module 81. A reflection film consisting of multiple layers of a range of thin dielectric film as shown in Table 2 is applied to the surface of the angled plane 89b.

TABLE 2

		Film thickness
Substrate	n = 1.635	—
1st layer	TiO_2	119 nm
2nd layer	SiO_2	183 nm
3rd layer	TiO_2	119 nm
4th layer	SiO_2	183 nm
5th layer	TiO_2	119 nm
6th layer	SiO_2	183 nm
7th layer	TiO_2	119 nm
8th layer	SiO_2	183 nm
9th layer	TiO_2	119 nm
10th layer	SiO_2	183 nm
11th layer	TiO_2	119 nm
12th layer	SiO_2	183 nm
13th layer	TiO_2	119 nm
14th layer	SiO_2	183 nm
15th layer	TiO_2	119 nm
16th layer	SiO_2	183 nm
17th layer	TiO_2	119 nm
18th layer	SiO_2	183 nm
19th layer	TiO_2	119 nm
20th layer	SiO_2	183 nm
21st layer	TiO_2	119 nm
22nd layer	SiO_2	183 nm
23rd layer	TiO_2	119 nm
24th layer	SiO_2	183 nm
25th layer	TiO_2	119 nm
26th layer	SiO_2	183 nm
27th layer	TiO_2	119 nm
28th layer	SiO_2	183 nm
29th layer	TiO_2	119 nm
30th layer	SiO_2	183 nm
31st layer	TiO_2	119 nm
32nd layer	SiO_2	183 nm
33rd layer	TiO_2	119 nm
Substrate	n = 1.635	—

A prism analyzer 90 has a trapezoidal cross-section, formed by bonding a prism having a triangular cross-section and a prism having a parallelogram cross-section. The prism analyzer 90 has a polarization splitting plane 90a at the junction plane of the above two prisms which is set to transmit approximately 100% of p-polarized light and reflect approximately 100% of s-polarized light. The prism analyzer 90 is disposed on the substrate 82 over the photo detector 86. The polarization splitting plane 90a is located over the component 86a of the photo detector 86, and an angled plane 90b is located over the component 86b of the photo detector 86. An object lens 91 is disposed over the polarizing prism 89 to focus the light.

In the magneto-optical pickup as configured above, p-polarized light emitted from the laser diode 83 is transmitted through the transparent substrate 87 on which the hologram diffraction grating 88 is formed, and enters the polarization splitting plane 89a of the polarizing prism 89. Since the polarization splitting plane 89a is set to transmit approximately 70% of p-polarized light, reflect approximately 30% of p-polarized light, and reflect approximately 100% of s-polarized light; approximately 70% of entering light is transmitted and focused by the object lens 91 on the magneto-optical recording medium 92. The polarization plane of light is rotated about 0.5° on the magneto-optical recording medium 92, depending on the type of recorded magnetic signals, for reflecting the light incorporating a small quantity of s-polarized light component as the magneto-optical signal component, following which the reflected light is transmitted through the object lens 91 again, and back to the polarization splitting plane 89a of the polarizing prism 89.

The polarization splitting plane 89a is set to transmit approximately 70% of p-polarized light, reflect approximately 30% of p-polarized light, and reflect approximately 100% of s-polarized light. Thus, approximately 70% of the p-polarized component is transmitted, and approximately 30% of the p-polarized component and 100% of the s-polarized component, which is the magneto-optical signal component, are reflected. Here, the components reflected on the polarization splitting plane 89a is reflected onto the angled plane 89b, passes through the transparent substrate 87 into the optical module 81, and enters the polarization splitting plane 90a of the prism analyzer 90. Since the polarization splitting plane 90a is set to transmit approximately 100% of p-polarized light and reflect approximately 100% of s-polarized light, the p-polarized light component passes through the polarization splitting plane 90a and enters the part 86a of the photo detector 86; the s-polarized component is reflected on the polarization splitting plane 90a, reflected on the angled plane 90b, and then enters the component 86b of the photo detector 86.

In the magneto-optical pickup as configured above, the polarizing prism 89 with different refractivity and transmittance for p-polarized light and s-polarized light is integrated into the optical module 81. The laser diode 83 and the photo detectors 84 to 86 are provided inside the optical module 81, and the prism analyzer 90 is integrated into the substrate 82. This configuration realizes a smaller, lower cost, and integrated optical pickup for magneto-optical disks.

Japanese Patent Application H7-188898 discloses a small optical pickup for DVDs as shown in FIGS. 12A and 12B. FIG. 12A shows a simplified sectional view of an optical system of the prior art, and FIG. 12B shows a magnified top view of a light receiving element.

In FIGS. 12A and 12B, an optical module 103 has a substrate 104 inside. A laser diode 105 and photo detectors 106, 107, and 108 are disposed on the substrate 104. The laser diode 105 is provided, for example, with a concave portion (not illustrated) having a 45° angled plane on a part of the substrate 104. A light emitting chip (not illustrated) is mounted inside, and light emitted from the light emitting chip is reflected on the 45° angled plane and radiated upwards. The laser diode emits linearly p-polarized light. The photo detectors 106 and 108 consist of four areas: 106a, 106b, 106c, and 106d; and 108a, 108b, 108c, and 108d respectively. The direction of the line that splits the areas 106b and 106d, and areas 108b and 108d is approximately parallel to the direction of the information tracks of a information recording medium 124. The transparent substrate 109 is made of glass or resin, and has a hologram diffraction grating 120 on the side facing the photo detectors 106, 107, and 108. A hologram diffraction grating 120 has a lens effect, giving ± primary diffraction light diffracted between approximately 5° and 20° to be focused close to and far from the transparent substrate 109 respectively, centering on the plane of the photo detectors 106, 107, and 108. The transparent substrate 109 is disposed to seal the inside of the optical module 103.

A polarization beam splitter 121 is formed by bonding a prism having an approximate right triangle cross-section and an approximate parallel prism having an approximate 45° cross-section. An optical film 121a which transmits p-polarized light and reflects s-polarized light is applied to the junction plane of the two prisms. The optical film 121a consists of multiple layers of multiple dielectric films as shown in Table 3.

TABLE 3

		Film thickness
Substrate	n = 1.51	—
1st layer	TiO_2	97 nm
2nd layer	SiO_2	152 nm
3rd layer	TiO_2	97 nm
4th layer	SiO_2	152 nm
5th layer	TiO_2	97 nm
6th layer	SiO_2	152 nm
7th layer	TiO_2	97 nm
8th layer	SiO_2	152 nm
9th layer	TiO_2	97 nm
Substrate	n = 1.51	—

The polarization beam splitter 121 is disposed on and integrated into the transparent substrate 109. An angled plane 121b inclines towards the inside of the optical module 103. A quarter-wave plate 122 is disposed on the surface of the polarization beam splitter 121 in an integrated fashion, where it converts linearly polarized light to circularly polarized light.

In the optical pickup as configured above, p-polarized light emitted from the laser diode 105 passes through the transparent substrate 109; enters the polarization beam splitter 121, passes through the optical film 121a, and enters the quarter-wave plate 122. The p-polarized light is converted to the circularly polarized light in the quarter-wave plate 122, and the circularly polarized light is focused on the information recording medium 124 by an object lens 123. The circularly polarized light reflected upon receiving the information signal on the information recording medium 124 passes through the object lens 123 again, and enters the quarter-wave plate 122. Here, the circularly polarized light is again converted to linearly polarized light which orthogonally crosses the p-polarized light emitted from the laser diode 105, i.e. s-polarized light, in the quarter-wave plate 122. The s-polarized light then enters the polarization beam splitter 121, is reflected on the optical film 121a and on the angled plane 121b, and enters the hologram diffraction grating 120 of the transparent substrate 109.

Here, the light is diffracted at diffraction angles of approximately 5° to 20°. The + primary diffraction light, for example, enters the photo detector 106, zero diffraction light enters the photo detector 107, and the − primary diffraction light enters the photo detector 108.

In the configuration of the optical pickup for DVDs as explained above, the optical module 103 and polarization beam splitter 121 are integrated, and the polarization beam splitter 121 and quarter-wave plate 122 are also integrated, offering drastically smaller optical pickups. Furthermore, the number of components has been reduced by integrating

the laser diode 105 and photo detectors 106, 107, and 108 into the optical module 103; and manufacturing costs have been reduced due to lack of need for extreme precision in the positioning of the photo detectors 106, 107, and 108.

Integration of components of optical pickups is achieved by employing a semiconductor laser which essentially generates diffused light, spreading to a certain range, as a light source. Therefore, the optical characteristics of components of optical pickups are strongly affected by the incident angle.

In the optical pickup for magneto-optical disks shown in FIGS. 11A and 11B, a phase difference may occur between the p-polarization light and s-polarization light responsive to broad incident angles because the polarization beam splitter film and reflection film disposed respectively on the face 89a of a glass material having an approximate parallelogram cross-section and the plane 89b which is approximately parallel to the plane 89a only consist of dielectric films.

FIG. 13 shows the phase difference between the p-polarized light and s-polarized light (hereafter referred to as the "p-s phase difference") of light reflected on the polarization beam splitter film, the p-s phase difference of light reflected on the reflection film, and the total of the p-s phase difference of the polarization beam splitter film and of the reflection film. This explains the dependence of the p-s phase difference on the incident angle when the light reflected on a disk enters a photo detector. As shown in FIG. 13, the p-s phase difference of the polarization beam splitter film is −50° to +40° when the light incident angle is ±10° with respect to the prism, therefore 45°±6° with respect to the optical film. The p-s phase difference of the reflection film exceeds −50° to +50° and the p-s phase difference of the light entering the photo detector (shown as the total p-s phase difference in FIG. 13) also exceeds −50° to +50°.

To satisfactorily reproduce the information recorded on a magneto-optical disk, the p-s phase difference when the light enters the photo detector may require to be within −20° to +20. With the polarization beam splitter film and reflection film of the prior art, it may be difficult to design an optical pickup which achieves the above preferable range for diffused light.

In the optical pickup for DVDs as shown in FIGS. 12A and 12B, transmittance of the p-polarized light in the polarization beam splitter film greatly depends on the incident angle, as shown in FIG. 14, when the light enters at a wide incident angle (the incident angle to the optical film is 45°±7° when the incident angle to the prism is 1°±0°). This may cause unsatisfactory reproduction due to reduced light entering the light receiving area.

Furthermore, since the hologram diffraction grating 120 is disposed on the transparent substrate 109 which seals the inside of the optical module, it may be necessary to broaden the diffraction angle θ of the diffracted light, i.e. to narrow the pitch of the diffraction grating, when the distance between the hologram diffraction grating 120 and photo detectors 106, 107, and 108 is short. This may cause difficulties in manufacturing such diffraction gratings, resulting in failure to achieve a satisfactory optical pickup.

SUMMARY OF THE INVENTION

The present invention offers a magneto-optical pickup which reduces the P-S phase difference.

The present invention further offers an optical pickup for DVDs which improves the light efficiency during reproduction and permits a wider diffraction grating.

A prism of the present invention and an optical pickup for magneto-optical disks employing the prism of the present invention comprises an approximate parallel prism having a polarization beam splitter disposed on an angled plane of a glass material having an approximate parallelogram cross-section and a reflection film on an angled plane which is approximately parallel to the angled plane on which the polarization beam splitter is disposed in the same glass material. The polarization beam splitter consists of a multi-layer film of a composite film made of a mixture of Si and SiO_{2-x} (x<0.5) (hereafter "composite film") and multiple layers of multiple dielectric films. The reflection film consists of a multi-layer film of a composite film made of a mixture of metal Si and oxide SiO_{2-x} (x<0.5) (hereafter "composite film") as high refractive film and multiple layers of multiple dielectric films as a relatively low refractive film.

In the approximate parallel prism of the magneto-optical pickup of the present invention, desirable refractive index n and absorption coefficient k of the composite film in the polarization beam splitter are n≧2.8 and k≦0.3.

In the approximate parallel prism of the optical pickup of the present invention, desirable diffraction index n and absorption coefficient k of the composite film in the reflection film are n≧2.8 and k≦0.3.

To achieve the aforementioned effect in an optical pickup for DVDs, the prism and optical pickup of the present invention comprises a parallel prism having a polarization beam splitter disposed on an angled plane of a glass material having an approximate parallelogram cross-section, a hologram diffraction grating disposed on an angled plane which is approximately parallel to an angled plane on which the polarization beam splitter is disposed, and a reflection film on the hologram diffraction grating. The polarization beam splitter consists of a multi-layer film of a composite film made of Si and SiO_{2-x} (x<0.5) and multiple layers of multiple dielectric films. The reflection film consists of a single metal film or multi-layer film of a metal film and dielectric film.

In the approximate parallel prism of the optical pickup of present invention, desirable refractive index n and absorption coefficient k of the composite film in the polarization beam splitter are n≧2.8 and k≦0.3.

The reflection film is preferably made of an Ag film. It is more preferable to form a patterned reflection film by precision processing.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a sectional view of a prism in accordance with a first exemplary embodiment of the present invention.

FIG. 2 shows the dependence on the incident angle of the p-s phase difference of a polarization beam splitter film in accordance with the first exemplary embodiment of the present invention.

FIG. 3 shows the dependence on the incident angle of the p-s phase difference of a reflection film in accordance with the first exemplary embodiment of the present invention.

FIG. 4 shows the dependence on the incident angle of the p-s phase difference of the light passing through the polarization beam splitter film and the reflection film in accordance with the first exemplary embodiment of the present invention.

FIG. 5 is a sectional view of an optical pickup in accordance with a second exemplary embodiment of the present invention.

FIG. 6 is a sectional view of a prism in accordance with a third exemplary embodiment of the present invention.

FIG. 7 shows the dependence on the incident angle of the transmittance of the prism in accordance with the third exemplary embodiment of the present invention.

FIG. 8 is a sectional view of an optical pickup in accordance with a fourth exemplary embodiment of the present invention.

FIG. 9 is a sectional view of a prism of an optical pickup in accordance with a fifth exemplary embodiment of the present invention.

FIG. 10 is a sectional view of an optical pickup in accordance with a sixth exemplary embodiment of the present invention.

FIG. 11A is a simplified sectional view of an optical system of the prior art.

FIG. 11B is a top view of FIG. 11A illustrating a light receiving element, light emitting element, and photo detector of the prior art.

FIG. 12A is a simplified sectional view of an optical system of the prior art.

FIG. 12B is a top view of FIG. 12A illustrating a light receiving element, light emitting element, and photo detector of the prior art.

FIG. 13 shows the dependence on the incident angle of the p-s phase difference of a prism of the prior art.

FIG. 14 shows the dependence on the incident angle of the transmittance of a polarization beam splitter film of the prior art.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

The present invention employs a parallel prism comprising a polarization beam splitter film on an angled plane of a glass material having an approximate parallelogram cross-section and a reflection film disposed on an angled plane approximately parallel to the angled plane on which the polarization beam splitter film is disposed. The polarization beam splitter film consists of a multi-layer film of a composite film made of a mixture of Si and SiO_{2-x} (x<0.5) and multiple layers of multiple dielectric films. The reflection film consists of a multi-layer film of a composite film made of a mixture of Si and SiO_{2-x} (x<0.5) as a high refractive film and multiple layers of multiple dielectric films as a relatively low refractive film. Changes in optical characteristics can be prevented although the light incident angle changes, by employing a composite film of a mixture of Si and SiO_{2-x} (x<0.5) in the polarization beam splitter film and reflection film. In other words, the composite film of the present invention has high refractive index n and low absorption coefficient k for reducing the dependence on the incident angle.

The refractive index n and absorption coefficient k of the composite film in the polarization beam splitter of the optical pickup of the present invention are n≧2.8 and k≦0.3. The refractive index n and absorption coefficient k of the composite film in the reflection film are also n≧2.8 and k≦0.3. The above values of the refractive index and absorption coefficients assure that the dependence on the incident angle is reduced and efficiency is improved.

The present invention according to one embodiment employs a parallel prism comprising a polarization beam splitter film disposed on an angled plane of a glass material having an approximate parallelogram cross-section, a hologram diffraction grating disposed on an angled plane in the same glass material approximately parallel to the angled plane on which the polarization beam splitter is disposed, and a reflection film disposed on the hologram diffraction grating. The polarization beam splitter film consists of a multi-layer film of a composite film made of a mixture of Si and SiO_{2-x} (x<0.5) and multiple layers of multiple dielectric films. The reflection film consists of a single metal film or a multi-layer film of a metal film and dielectric film.

Changes in optical characteristics can be prevented, although the light incident angle changes, by employing the composite film made of a mixture of Si and SiO_{2-x} (x<0.5) in the polarization beam splitter film. In other words, the composite film of the present invention has high refractive index n and low absorption coefficient for reducing the dependence on the incident angle. Since the hologram grating is disposed on the parallel prism, the optical distance between the hologram grating and the photo detector can be made longer, enabling the reduction of the diffraction angle θ of the hologram diffraction grating. This allows broader pitch of the hologram pattern for facilitating the creation of hologram grating in production.

The present invention according to another embodiment is an optical pickup in which the metal film in the polarization beam splitter has the refractive index n of n≧2.8 and the absorption coefficient k of k≦0.3. The dependence on the incident angle and efficiency can be improved by limiting the refractive index n and absorption coefficient k to the above ranges.

In one aspect of the present invention the metal film in the reflection film is made of Ag. The use of Ag for the metal film of the reflection film reduces the dependence of the reflectance on the incident angle and improves reflectance.

The present invention according to still another embodiment is an optical pickup comprising a patterned reflection film at least on the hologram diffraction grating by providing the reflection film only on the hologram diffraction grating. Peeling of the reflection film can be thus suppressed and satisfactory optical pickup can be realized although the reflection film and glass material show poor adhesivity.

The present invention according to another embodiment employs a parallel prism comprising a polarization beam splitter disposed on an angled plane of a parallelogram glass material having an approximate 45° cross-section and a hologram diffraction grating disposed on an angled plane approximately parallel to the angled plane on which the polarization beam splitter is disposed in the same glass material. The polarization beam splitter film consists of a multi-layer of a composite film made of a mixture of Si and SiO_{2-x} (x<0.5) and multiple layers of multiple dielectric films. The refractive index n of the glass material is n≧1.6. A small optical pickup with higher efficiency and smaller dependence on the incident angle can be achieved without using a reflection film for adjusting the reflectance of the hologram diffraction grating.

According to one aspect of the above embodiment, the present invention is an optical pickup in which the refractive index n, absorption coefficient k, and total thickness d of the metal film in the polarization beam splitter is set to n≧2.8 and k≦0.3. The dependence on the incident angle and efficiency can be improved by limiting the refractive index n and absorption coefficient k to the above ranges.

The exemplary embodiments of the present invention are explained with reference to FIGS. 1 to 10 next.

First Exemplary Embodiment

FIG. 1 shows a sectional view of a prism employed in an optical pickup for magneto-optical disks in a first exemplary embodiment of the present invention. FIGS. 2 to 4 show the dependence on the incident angle of the p-s phase difference of the prism.

As shown in FIG. 1, a prism 1 comprises a parallelogram-shaped glass material 2 having an approximate 45° cross-

section. The refractive index n of the glass material 2 is 1.635. A polarization beam splitter film 4 consisting of a composite film made of a mixture of Si and SiO_{2-x} (x=0.2) (hereafter "composite film"), and multiple layers of multiple dielectric films such as Al_2O_3, SiO_2, Y_2O_3, and TiO_2 films, shown in Table 4 and Table 5, is disposed on an angled plane 3 of the glass material 2.

TABLE 4

		Film thickness
Substrate	n = 1.635	—
1st layer	Al_2O_3	390 nm
2nd layer	$Si + SiO_{2-x}$	25 nm
3rd layer	Al_2O_3	324 nm
4th layer	$Si + SiO_{2-x}$	25 nm
5th layer	Al_2O_3	390 nm
6th layer	SiO_2	186 nm
7th layer	Y_2O_3	166 nm
8th layer	SiO_2	185 nm
9th layer	Y_2O_3	101 nm
10th layer	SiO_2	186 nm
Substrate	n = 1.635	—

$Si + SiO_{2-x}$: n = 3.5, k = 0.04 (x = 0.2)

TABLE 5

		Film thickness
Substrate	n = 1.635	—
1st layer	Al_2O_3	262 nm
2nd layer	$Si + SiO_{2-x}$	40 nm
3rd layer	Al_2O_3	262 nm
4th layer	$Si + SiO_{2-x}$	40 nm
5th layer	Al_2O_3	388 nm
6th layer	SiO_2	190 nm
7th layer	Al_2O_3	196 nm
8th layer	SiO_2	190 nm
9th layer	Al_2O_3	156 nm
10th layer	SiO_2	190 nm
Substrate	n = 1.635	—

$Si + SiO_{2-x}$: n = 2.9, k = 0.03 (x = 0.2)

The polarization beam splitter film 4 shown in Tables 4 and 5 consists of a 10-layer film.

A reflection film 6, comprising a multi-layer film of a composite film made of Si and SiO_{2-x} (x=0.2) (hereafter "composite film) as high refractive index film and multiple layers of multiple dielectric films, which have relatively low refractive index such as Al_2O_3 and TiO_2 films, is disposed on an angled plane 5 which is approximately parallel to the angled plane 3 in the same glass material 2.

TABLE 6

		Film thickness
Substrate	n = 1.635	—
1st layer	Al_2O_3	295 nm
2nd layer	$Si + SiO_{2-x}$	60 nm
3rd layer	TiO_2	106 nm
4th layer	$Si + SiO_{2-x}$	60 nm
5th layer	TiO_2	106 nm
6th layer	$Si + SiO_{2-x}$	60 nm
7th layer	TiO_2	106 nm
8th layer	$Si + SiO_{2-x}$	60 nm
9th layer	TiO_2	106 nm
10th layer	$Si + SiO_{2-x}$	60 nm
11th layer	TiO_2	106 nm
12th layer	$Si + SiO_{2-x}$	60 nm
13th layer	TiO_2	106 nm
14th layer	$Si + SiO_{2-x}$	60 nm
15th layer	TiO_2	106 nm

TABLE 6-continued

		Film thickness
16th layer	$Si + SiO_{2-x}$	60 nm
17th layer	TiO_2	106 nm
18th layer	$Si + SiO_{2-x}$	60 nm
19th layer	TiO_2	106 nm
20th layer	$Si + SiO_{2-x}$	60 nm
21st layer	TiO_2	106 nm
22nd layer	$Si + SiO_{2-x}$	60 nm
23rd layer	Al_2O_3	295 nm
Substrate	n = 1.635	—

$Si + SiO_{2-x}$: n = 3.5, k = 0.04 (x = 0.2)

TABLE 7

		Film thickness
Substrate	n = 1.635	—
1st layer	Al_2O_3	354 nm
2nd layer	$Si + SiO_{2-x}$	60 nm
3rd layer	TiO_2	127 nm
4th layer	$Si + SiO_{2-x}$	60 nm
5th layer	TiO_2	127 nm
6th layer	$Si + SiO_{2-x}$	60 nm
7th layer	TiO_2	127 nm
8th layer	$Si + SiO_{2-x}$	60 nm
9th layer	TiO_2	127 nm
10th layer	$Si + SiO_{2-x}$	60 nm
11th layer	TiO_2	127 nm
12th layer	$Si + SiO_{2-x}$	60 nm
13th layer	TiO_2	127 nm
14th layer	$Si + SiO_{2-x}$	60 nm
15th layer	TiO_2	127 nm
16th layer	$Si + SiO_{2-x}$	60 nm
17th layer	TiO_2	127 nm
18th layer	$Si + SiO_{2-x}$	60 nm
19th layer	TiO_2	127 nm
20th layer	$Si + SiO_{2-x}$	60 nm
21st layer	TiO_2	127 nm
22nd layer	$Si + SiO_{2-x}$	60 nm
23rd layer	Al_2O_3	354 nm
Substrate	n = 1.635	—

$Si + SiO_{2-x}$: n = 2.9, k = 0.03 (x = 0.2)

The reflection film 6 shown in Tables 6 and 7 is a 23-layer film.

Triangular prisms 7 and 8 are disposed on both sides of the glass material 2, and they are respectively bonded through the polarization beam splitter film 4 and the reflection film 6.

FIG. 2 shows the dependence of the p-s phase difference of the reflection light on the incident angle at the polarization beam splitter film 4 comprising a multi-layer film, and FIG. 3 shows the dependence of the p-s phase difference of the reflection light on the incident angle at the reflection film only. FIG. 4 shows the total p-s phase difference of the reflection light at the polarization beam splitter film and reflection film, in other words, the dependence on the incident angle of the light reflected on the disk entering the photo detector. In FIG. 2, the light incident angle is plotted along the abscissa, and this is the angle created between a normal plane 3 of the polarization beam splitter film 4 and the entering light. In FIG. 3, the angle created between a normal plane 5 of the reflection film and the entering light is plotted along the abscissa.

It is apparent from FIGS. 2, 3, and 4 that the p-s phase difference at the polarization beam splitter film 4 is −10° to +10° (prior art: −50° to +40°) when the light incident angle against the prism is ±10, i.e. 45°±6° against an optical film, compared to the polarization beam splitter film and reflection film of the prior art comprising only multiple dielectric

layers shown in FIG. 13. The p-s phase difference of the reflection film is −20° to +10° (prior art: −50° to +40°), and the p-s phase difference of the light entering the photo detector is −15° to +20° (prior art: −50° to +50°). The p-s phase difference may accordingly be reduced.

As for the composite film in the polarization beam splitter film and reflection film consisting of a mixture of Si and SiO_{2-x}, "x=0.2" is used as an example. The same characteristics can be achieved as long as x is 0<x<0.5.

Although it is not illustrated, it is apparent that the dependence of transmittance and reflectance on the incident angle is smaller because the refractive index n is large, and that high transmittance can be achieved because the absorption coefficient k is small.

Desirable phase characteristics can be thus achieved because a multi-layer film of a dielectric film and metal film basically complement mutual characteristics. Specifically, the dielectric film has no absorption loss in the film and its transmittance and reflectance can be freely adjusted by changing the composition of multiple materials, but its optical characteristics such as phase difference largely differ depending on the light incident angle. On the other hand, the optical characteristics of the metal film do not relatively change even the light incident angle changes because of its large refractive index, but it is difficult to achieve high transmittance with the metal film due to its large absorption coefficient. Accordingly, transmittance and reflectance can be freely adjusted, and dependence on light incident angle can be made smaller by alternately layering dielectric and metal films with complementary mutual characteristics. In the present invention, the composite film consisting of a mixture of Si and its SiO_{2-x} is employed instead of a simple metal film. This realizes a high refractive index n and a low absorption coefficient k for enabling a highly efficient polarization beam splitter film and reflection film.

The refractive index and absorption coefficient k of the composite film in the polarization beam splitter film, consisting of a mixture of Si and its SiO_{2-x} in the polarization beam splitter film, affect the dependence of the p-s phase difference of the reflected light on the incident angle as shown in FIGS. 2 to 4. As mentioned above, larger refractive index n and a smaller absorption coefficient k are preferred for the composite film, and to be more specific, n≧2.8 and k≦0.3 are desirable. This is because if n<2.8, the p-s phase difference of the light entering the photo detector may not fall within −20° to +20°, the essential prerequisite for desirable reproduction from recorded magneto-optical disks. If k>0.3, efficiency may fall.

In this exemplary embodiment, the angle of the glass material 2 is set to approximately 45°; however, the p-s phase difference characteristics of the reflected light related to the incident angle can be improved over those of a conventional multi-layer film as long as the angle of the glass material 2 is set within 35° to 55° and the above multi-layer film of the present invention is disposed on the angled plane 3 and the angled plane 5 which is approximately parallel to the angled plane 3.

Second Exemplary Embodiment

FIG. 5 shows a simplified sectional view of an optical pickup in a second exemplary embodiment of the present invention employing a prism in the first exemplary embodiment of the present invention. The prism in accordance with the first exemplary embodiment of the present invention is built into the optical pickup for magneto-optical disk shown in FIGS. 11A and 11B. This exemplary embodiment thus achieves improved reproduction from recorded magneto-optical disks by reducing the p-s phase difference.

Third Exemplary Embodiment

FIG. 6 shows a prism which is employed in an optical pickup for DVDs in a third exemplary embodiment of the present invention. FIG. 7 shows basic performance of the prism in this exemplary embodiment, i.e. transmittance of a polarization beam splitter film against p-polarized light.

As shown in FIG. 6, a prism 50 comprises a parallelogram-shaped glass material 51 having an approximate 45° cross-section. The refractive index n of the glass material 51 is 1.51. A polarization beam splitter film 53 comprising a multi-layer of a composite film made of Si and SiO_{2-x} (x=0.2) and multiple layers of multiple dielectric films such as Al_2O_3, SiO_2, Y_2O_3, and TiO_2 films, shown in Table 8 and Table 9, is disposed on an angled plane 52 of the glass material 51.

TABLE 8

		Film thickness
Substrate	n = 1.51	—
1st layer	TiO_2	42 nm
2nd layer	SiO_2	75 nm
3rd layer	TiO_2	89 nm
4th layer	SiO_2	75 nm
5th layer	TiO_2	89 nm
6th layer	SiO_2	75 nm
7th layer	TiO_2	89 nm
8th layer	SiO_2	110 nm
9th layer	TiO_2	89 nm
10th layer	SiO_2	75 nm
11th layer	TiO_2	89 nm
12th layer	SiO_2	75 nm
13th layer	TiO_2	89 nm
14th layer	SiO_2	110 nm
15th layer	TiO_2	114 nm
16th layer	SiO_2	248 nm
17th layer	$Si + SiO_{2-x}$	30 nm
18th layer	TiO_2	42 nm
19th layer	SiO_2	219 nm
20th layer	TiO_2	89 nm
Substrate	n = 1.51	—

$Si + SiO_{2-x}$: n = 3.7, k = 0.17 (x = 0.2)

TABLE 9

		Film thickness
Substrate	n = 1.51	—
1st layer	TiO_2	31 nm
2nd layer	SiO_2	85 nm
3rd layer	TiO_2	83 nm
4th layer	SiO_2	85 nm
5th layer	TiO_2	83 nm
6th layer	SiO_2	85 nm
7th layer	TiO_2	83 nm
8th layer	SiO_2	120 nm
9th layer	TiO_2	83 nm
10th layer	SiO_2	85 nm
11th layer	TiO_2	83 nm
12th layer	SiO_2	85 nm
13th layer	TiO_2	83 nm
14th layer	SiO_2	120 nm
15th layer	TiO_2	107 nm
16th layer	SiO_2	245 nm
17th layer	$Si + SiO_{2-x}$	45 nm
18th layer	TiO_2	31 nm
19th layer	SiO_2	204 nm
20th layer	TiO_2	83 nm
Substrate	n = 1.51	-

$Si + SiO_{2-x}$: n = 3.1, k = 0.08 (x = 0.2)

The polarization beam splitter film 53 shown in Tables 8 and 9 consists of a 20-layer film.

A hologram diffraction grating 55 is disposed on an angled plane 54 which is approximately parallel to the

angled plane 52 in the same glass material 51. A reflection film 56 made of Ag is disposed on the hologram diffraction grating 55.

Triangular prisms 57 and 58 are disposed on both sides of the glass material 51, and they are respectively bonded through the polarization beam splitter film 53 and the reflection film 56.

FIG. 7 shows changes of the transmittance of the p-polarized light according to the light incident angle of the polarization beam splitter film 53 comprising a multi-layer film of the present invention. The transmittance of the polarization beam splitter film 53 is 79% to 90% (incident angle: 45°±7°). It is apparent that the transmittance is stabilized at small transition compared to that of the prior art, as shown in FIG. 14, which is 50% to 100%.

In FIG. 7, the light incident angle is plotted along the abscissa, and this is the angle created between the normal angled plane 52 of the polarization beam splitter film 53 and the entering light.

As for the composite film in the polarization beam splitter film and reflection film consisting of a mixture of Si and SiO_{2-x}, "x=0.2" is used as an example. The same characteristics can be achieved as long as x is 0<x<0.5.

Stabilized transmittance for the p-polarized light regardless of the incident angle can be achieved because a multi-layer film of a dielectric film and metal film basically complement mutual characteristics, as already explained in the first exemplary embodiment. In addition, high refractive index n and low absorption coefficient k can be achieved by employing a composite film consisting of a mixture of Si and its SiO_{2-x} instead of a single metal film.

The refractive index and absorption coefficient k of the composite film in the polarization beam splitter film, consisting of a mixture of Si and SiO_{2-x}, affect the dependence of the p-s phase difference of the reflected light on the incident angle as shown in FIG. 7. A larger refractive index n and smaller absorption coefficient k for a composite film are preferred, and to be more specific, n≧2.8, k≦0.3 are desirable.

Since the hologram diffraction grating 55 is disposed on the angled plane 54 which is approximately parallel to the angled plane 52 of the glass material 51, the optical distance between the hologram optical element and the photo detector can be made longer than that in the prior art shown in FIGS. 11A and 11B, enabling the reduction of the diffraction angle θ of the hologram diffraction grating 55. This allows broader pitch of the hologram pattern for facilitating the creation of hologram grating in production.

Furthermore, the dependence of reflectance on the incident angle can be reduced and high reflectance can be achieved by using Ag for the metal film of the reflection film.

By providing a patterned reflection film at least on the hologram diffraction grating 55, peeling of the reflection film can be suppressed and desirable optical pickup can be achieved, in spite of poor adhesivity of the reflection film to the glass material.

This exemplary embodiment employs a parallelogram-shaped glass material 51 having an approximate 45° cross-section. However, the transmittance of p-polarized light depending on the incident angle can be stabilized, compared to the approximate parallel prism using a multi-layer film of the prior art, as long as the angle is between 35° to 55° by disposing the multi-layer film 53 on the angled plane 52, the hologram diffraction grating 55 on the angled plane 54 approximately parallel to the angled plane 52, and the reflection film 56 on the hologram diffraction grating 55.

Fourth Exemplary Embodiment

FIG. 8 shows a simplified sectional view of an optical system of an optical pickup in a fourth exemplary embodiment of the present invention employing a prism in accordance with the third exemplary embodiment of the present invention. In this exemplary embodiment, a prism in the third exemplary embodiment is mounted on the transparent substrate 109 without the hologram diffraction grating 120 of the optical pickup shown in FIGS. 12A and 12B. At measuring the characteristics for reproduction of DVDs employing the optical pickup of this exemplary embodiment, desirable reproduction has been achieved due to the increase in light efficiency by stabilizing the p-polarized light transmittance against the incident angle compared to the optical pickup of the prior art.

Fifth Exemplary Embodiment

FIG. 9 shows a sectional view of a parallel prism, having an approximate 45° cross-section, employed in a pickup for DVDs in a fifth exemplary embodiment of the present invention.

As shown in FIG. 9, a prism 70 comprises a glass material 71 having an approximate parallelogram cross-section and a glass material 76 having an approximate triangular cross-section. The refractive index n of the glass material 71 having an approximate parallelogram cross-section is 1.6. A polarization beam splitter film 73 comprising a multi-layer film of a composite film made of Si and SiO_{2-x} (x=0.2), and multiple layers of multiple dielectric films such as Al_2O_3, SiO_2, Y_2O_3, and TiO_2 films, shown in Table 8 and Table 9, is disposed on an angled plane 72 of the glass material 71. The polarization beam splitter film 73 shown in Tables 8 and 9 consists of a 20-layer film.

A hologram diffraction grating 75 is disposed on an angled plane 74 approximately parallel to the angled plane 72 in the same glass material 71.

Triangular prism 76 is disposed on the side of the polarization beam splitter film 73 on the glass material 71, and it is bonded through the polarization beam splitter film 73.

The effect of employing the multi-layer film for the polarization beam splitter film 73 in this exemplary embodiment is the same as that in the second exemplary embodiment, and thus the explanation for the effect is omitted here.

As for the composite film in the polarization beam splitter film and reflection film consisting of a mixture of Si and SiO_{2-x}, "x=0.2" is used as an example. The same characteristics can be achieved as long as x is 0<x<0.5.

The refractive index n and absorption coefficient k of the composite film in the polarization beam splitter film 73, consisting of a mixture of Si and its SiO_{2-x}, affect the dependence of the p-s phase difference of the reflected light on the incident angle as shown in FIG. 7. A larger refractive index n and smaller absorption coefficient k for a composite film is preferred, and to be more specific, n≧2.8, k≦0.3 are desirable, as explained in the third exemplary embodiment.

Since the hologram grating is disposed on the angled plane 74 which is approximately parallel to the angled plane 72 of the glass material 71, the optical distance between the hologram grating 55 and the photo detector can be made longer than that in the prior art shown in FIGS. 12A and 12B, enabling the reduction of the diffraction angle θ of the hologram grating. This allows broader pitch of the hologram pattern for facilitating the creation of hologram grating in production. This is also the same as the third exemplary embodiment.

The fifth exemplary embodiment may not require the reflection film 56 and triangular prism 58 which are employed in the third exemplary embodiment because the angle of the glass material 71 is approximately 45° and its refractive index is 1.6 in this exemplary embodiment for achieving desirable reflection characteristics for reflection on the glass material 71/air surface. Desirable reflection characteristics can be achieved when the refractive index n of the glass material 71 is n≧1.6.

Sixth Exemplary Embodiment

FIG. 10 shows a simplified sectional view of the optical system of the optical pickup in a sixth exemplary embodiment employing a prism of the fifth exemplary embodiment of the present invention. In this exemplary embodiment, the prism in the fifth exemplary embodiment is mounted on the transparent substrate 109 without the hologram grating 120 of the optical pickup shown in FIGS. 12A and 12B. At measuring the characteristics for reproduction of DVDs employing the optical pickup of this exemplary embodiment, desirable reproduction has been achieved due to the increase in light efficiency by stabilizing the p-polarized light transmittance against the incident angle, compared to the optical pickup of the prior art.

As described above, the prism and the optical pickup employing such prism of the present invention greatly reduces the p-s phase difference and achieves desirable reproduction without increasing the dependence of the reflectance and transmittance on the incident angle.

Since the hologram grating is disposed on the parallel prism in the prism of the present invention and the optical pickup employing such prism, the optical distance between the hologram optical element and the photo detector can be made longer than that in the prior art, enabling the reduction of the diffraction angle θ of the hologram diffraction grating. This allows broader pitch of the hologram pattern for facilitating the creation of hologram grating in production. Furthermore, the dependence of reflectance on the incident angle can be reduced and high reflectance can be achieved by using Ag for the metal film of the reflection film. By also providing a patterned reflection film at least on the hologram diffraction grating, peeling of the reflection film can be suppressed and desirable optical pickup can be achieved, in spite of poor adhesivity of the reflection film to the glass material.

Desirable reflection characteristics for reflection on the glass material 71/air surface can also be achieved by employing a parallel prism having an approximate 45° cross-section and setting the refractive index n to 1.6 or above.

What is claimed is:

1. A prism for optical pickups, comprising:
   - a glass material having an approximate parallelogram cross-section and having a first angled plane and a second angled plane approximately parallel to each other;
   - a multi-layer film disposed on said first angled plane of the glass material, said multi-layer film comprising a composite film comprising a mixture of Si and SiO_{2-x}, wherein x<0.5, and multiple layers of multiple dielectric films; and
   - a multi-layer film disposed on said second angled plane of the glass material, said multi-layer film comprising a composite film comprising of a mixture of Si and SiO_{2-x}, wherein x<0.5, as a high refractive film and multiple layers of multiple dielectric films as a relatively low refractive film.

2. A prism for optical pickups as defined in claim 1, further comprising:
   - a first triangular prism bonded to said multi-layer film formed on said first angled plane of the glass material; and
   - a second triangular prism bonded to said multi-layer film formed on said second angled plane of the glass material.

3. A prism for optical pickups as defined in claim 1, wherein said dielectric films include at least one of Al_2O_3, SiO_2, Y_2O_3, and TiO_2.

4. A prism for optical pickups as defined in claim 1, wherein said composite film disposed on said first angled plane of the glass material has a refractive index n≧2.8 and an absorption coefficient k≦0.3, and said composite film disposed on said second angled plane of the glass material has a refractive index n≧2.8 and an absorption coefficient k≦0.3.

5. An optical pickup comprising the prism of claim 1, wherein said multi-layer film disposed on said first angled plane of the glass material is a polarization beam splitter and said multi-layer film disposed on said second angled plane of the glass material is a reflection film.

6. An optical pickup as defined in claim 5, wherein the refractive index n and absorption coefficient k of the composite film in a polarization beam splitter are n≧2.8 and k≦0.3, and the refractive index n and absorption coefficient k of the composite film reflection film are n≧2.8 and k≦0.3.

7. A prism for optical pickups, comprising:
   - a glass material having an approximate parallelogram cross-section and having a first angled plane and a second angled plane approximately parallel to each other, and a hologram diffraction grating disposed on said second angled plane;
   - a multi-layer film disposed on said first angled plane of the glass material, said multi-layer film comprising a composite film comprising a mixture of Si and SiO_{2-x}, wherein x<0.5 and multiple layers of multiple dielectric films; and
   - a multi-layer film disposed on said hologram diffraction grating on said second angled plane of the glass material, said multi-layer film comprising at least metal.

8. A prism for optical pickups as defined in claim 7, further comprising:
   - a first triangular prism bonded to said multi-layer film formed on said first angled plane of the glass material; and
   - a second triangular prism bonded to said multi-layer film formed on said second angled plane of the glass material.

9. A prism for optical pickups as defined in claim 7, wherein said dielectric films include at least one of Al_2O_3, SiO_2, Y_2O_3, and TiO_2.

10. A prism for optical pickups as defined in claim 7, wherein the refractive index n and absorption coefficient k of the composite film disposed on said first angled plane of the glass material are n≧2.8 and k≦0.3; and the refractive index n and absorption coefficient k of the film formed on said second angled plane of the glass material are n≧2.8 and k≦0.3.

11. An optical pickup, comprising:
   - a glass material having an approximate parallelogram cross-section and having a first angled plane and a second angled plane approximately parallel to each other, and a hologram diffraction grating disposed on said second angled plane;
   - a multi-layer film disposed on said first angled plane of the glass material, said multi-layer film comprising a composite film comprising a mixture of Si and SiO_{2-x}, wherein x<0.5, and multiple layers of multiple dielectric films; and

a multi-layer film disposed on said hologram diffraction grating on said second angled plane of the glass material, said multi-layer film comprising at least metal;

wherein said multi-layer film disposed on said first angled plane of the glass material is a polarization beam splitter and said multi-layer film disposed on said second angled plane of the glass material is a reflection film.

12. An optical pickup employing a parallel prism, comprising:

a multi-layer film disposed on an angled plane of a glass material having an approximate parallelogram cross-section, said multi-layer film being a polarization beam splitter and comprising a composite film comprising a mixture of Si and SiO_{2-x}, wherein x<0.5, and multiple layers of multiple dielectric films;

a hologram diffraction grating disposed on an angled plane of the same glass material approximately parallel to the angled plane on which said polarized beam splitter is disposed; and

a multi-layer film disposed on said hologram diffraction grating, said multi-layer film comprising one of a single metal film and multi-layer metal and dielectric film.

13. An optical pickup as defined in claim 12, wherein the refractive index n and absorption coefficient k of the metal film in the polarization beam splitter are n≧2.8 and k≦0.3.

14. An optical pickup as defined in claim 12, wherein the single metal film is an Ag reflection film.

15. An optical pickup as defined in claim 14, wherein the reflection film is patterned and at least disposed on said hologram diffraction grating.

16. A prism for optical pickups, comprising:

a glass material having an approximate parallelogram cross-section and having a first angled plane and a second angled plane approximately parallel to each other, and a hologram diffraction grating disposed on said second angled plane;

a multi-layer film disposed on said first angled plane of the glass material, said multi-layer film comprising a composite film comprising a mixture of Si and SiO_{2-x}, wherein x<0.5, and multiple layers of multiple dielectric films; and

an Ag film disposed on said hologram diffraction grating on said second angled plane of the glass material.

17. A prism for optical pickups as defined in claim 16, further comprising a first triangular prism bonded to said multi-layer film disposed on said first angled plane of the glass material.

18. A prism for optical pickups as defined in claim 16, wherein said dielectric films include at least one of Al_2O_3, SiO_2, Y_2O_3, and TiO_2.

19. A prism for optical pickups as defined in claim 16, wherein said composite film disposed on said first angled plane of the glass material has a refractive index n≧2.8 and an absorption coefficient k≦0.3.

20. An optical pickup, comprising:

a glass material having an approximate parallelogram cross-section and having a first angled plane and a second angled plane approximately parallel to each other, and a hologram diffraction grating disposed on said second angled plane;

a multi-layer film disposed on said first angled plane of the glass material, said multi-layer film comprising a composite film comprising a mixture of Si and SiO_{2-x}, wherein x<0.5, and multiple layers of multiple dielectric films; and

an Ag film disposed on said hologram diffraction grating on said second angled plane of the glass material,

wherein said multi-layer film disposed on said first angled plane of the glass material is a polarization beam splitter, and said Ag film disposed on said second angled plane of the glass material is a reflection film.

21. An optical pickup as defined in 20, wherein the refractive index n and absorption coefficient k of the metal film in the polarization beam splitter are n≧2.8 and k≦0.3.

22. An optical pickup employing a parallel prism, comprising:

a multi-layer film disposed on an angled plane of a parallelogram-shaped glass material having an approximate 45° cross-section, said multi-layer film being a polarization beam splitter and comprising a composite film comprising a mixture of Si and SiO_{2-x}, wherein x<0.5, and multiple layers of multiple dielectric films; and

a hologram diffraction grating disposed on an angled plane of the same glass material approximately parallel to the angled plane on which said polarized beam splitter is disposed,

wherein the refractive index of the glass material is n≧1.6.

23. An optical pickup as defined in claim 22, wherein the refractive index n and absorption coefficient k of a metal film in the polarization beam splitter are n≧2.8 and k≦0.3.

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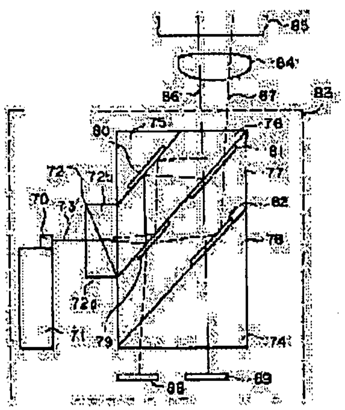
(71)Applicant : MATSUSHITA ELECTRIC IND CO LTD
(72)Inventor : GOTO HIROSHI

(54) MULTIBEAM GENERATING METHOD AND MULTIBEAM OPTICAL PICKUP

(57)Abstract
PROBLEM TO BE SOLVED: To provide a small multibeam optical pickup at low cost capable of generating plural beams from a semiconductor laser having one light emitting point and simultaneously reproducing plural tracks.
SOLUTION: This optical pickup is composed of a semiconductor laser 70 having one light emitting point, a prallel plane plate wedge member 72 oppositely joining wedge-like birefringent members to each other, a laminated prism 74 integrally forming plural parallel plane plates, having a grating in one part of the joined surface, a polarizing beam splitter 82 in the other part of the joined surface and plural photodetectors and they are formed in one package. Consequently, the parts from the semiconductor laser to the photodetectors are integrally built-up and a multibeam generating method and a small multibeam optical pickup at low cost are obtained.



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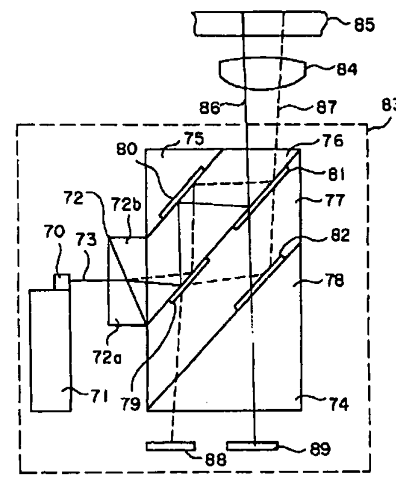
(71)出願人　000005821
松下電器産業株式会社
大阪府門真市大字門真1006番地
(72)発明者　後藤　博志
大阪府門真市大字門真1006番地　松下電器産業株式会社内
(74)代理人　弁理士　滝本　智之　(外1名)

(54)【発明の名称】マルチビーム生成方法及びマルチビーム光ピックアップ

(57)【要約】
【課題】　一つの発光点を有する半導体レーザから複数のビームを生成し、複数のトラックを同時に再生することのできる小型で低コストなマルチビーム光ピックアップを提供することを目的とする。
【解決手段】　本発明の光ピックアップは、1つの発光点を有する半導体レーザ70と、くさび状の複屈折部材を互いに逆向きに接合した平行平板くさび部材72と、複数の平行平板を一体に成型し、その接合面の一部にグレーティングとその接合面の他の一部に偏光ビームスプリッタ82とを有するラミレートプリズム74と、複数の受光素子とを一つのパッケージに形成して構成した。よって、半導体レーザから受光素子までを一体に組み込むことができ、小型で低コストのマルチビーム生成方法及びマルチビーム光ピックアップが得られる。



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【特許請求の範囲】

【請求項1】１つの発光点から出射した１本のレーザ光を、くさび状の複屈折部材を互いに逆向きに接合した平行平板くさび部材に透過させるステップと、複数の平行平板が一体に成型されたラミレートプリズム部材であって、その接合面の一部に設けられたグレーティングを反射するステップと、その接合面の他の一部に設けられた偏光ビームスプリッタを透過、または反射するステップと、前記偏光ビームスプリッタを透過したビームと、前記偏光ビームスプリッタを反射したビームとを互いに別の受光素子に受光するステップとを有し、前記１本のレーザ光を前記平行平板くさび部材により２本のビームに分割し、さらに前記グレーティングにより２本のビームをそれぞれ３分割し合計６本のビームとして前記ラミネートプリズム部材より出射させ、被検出面から反射した入射光をその偏光面に応じて前記偏光ビームスプリッタにより３本ずつ２つのグループに分離して前記受光素子により受光することを特徴とするマルチビーム生成方法。

【請求項2】１つの発光点を有するレーザ光源と、くさび状の複屈折部材を互いに逆向きに接合した平行平板くさび部材と、複数の平行平板を一体に成型し、その接合面の一部にグレーティングと、その接合面の他の一部に偏光ビームスプリッタとを有するラミレートプリズム部材と、複数の受光素子とを有し、前記レーザ光源の１本のビームを前記平行平板くさび部材により２本のビームに分割し、さらに前記グレーティングにより２本のビームをそれぞれ３分割し合計６本のビームとして前記ラミネートプリズム部材より出射させ、被検出面から反射した入射光をその偏光面に応じて前記偏光ビームスプリッタにより３本ずつ２つのグループに分離して前記受光素子により受光することを特徴とするマルチビーム光ピックアップ。

【発明の詳細な説明】

【0001】

【発明の属する技術分野】本発明は、光学的情報記録媒体に対して複数のトラックから同時に情報を再生するためのマルチビーム生成方法及びマルチビーム光ピックアップに関するものである。

【0002】

【従来の技術】近年、レーザ光により光学的情報記録媒体（光ディスク）上の情報を再生する装置は著しい発達をしている。また、コンピュータで取り扱うデータも、コードデータから音楽、静止画像、動画と進展するにつれ、データ量も増大している。それに伴って、光ディスクの情報再生装置からホストコンピュータにデータを転送するスピードの高速化が要求されている。データ転送レートを高速化するために、従来は光ディスクの回転数を上げる手法がもっぱら行われていた。

【0003】しかしながらこの方法では、光ディスクを

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回転駆動するモータの回転数を大幅に上げるためにモーターを大型化しなければならないとか回転数の上昇に伴って光ディスクの振動や面振れが大きくなりサーボ系の安定化が困難になる等の問題が生じている。

【0004】そこで、情報の読み取りを行う光ピックアップで複数のレーザビームを発生させ、光ディスクに対して複数のトラックから同時に情報の再生を行うマルチビーム光ピックアップが提案されている。この方法では、モータを大型化する必要もなく、さらに回転数の上昇に伴うディスクの振動や面振れも押さえることが可能であるため、有望視されている。

【0005】以下、図に基づき従来のマルチビーム光ピックアップの技術を説明する。図３は従来のマルチビーム光ピックアップの構成図である。図において、半導体レーザ４０には２個のレーザチップ４１、４２があり、２本のビームを発光している。これらの２本のビームはコリメートレンズ２により平行光となり、グレーティング３により３ビーム化され合計６本のビームがハーフミラー８を通り、対物レンズ９により集光され光ディスク１０に照射される。光ディスク１０からの反射光は、再び対物レンズ９を通りハーフミラー８で反射され、検出レンズ４３、シリンドリカルレンズ４４を通り、受光素子４５に入射する。フォーカス検出は公知の非点収差法により、トラック検出は公知の３ビーム法により行われる。

【0006】図４は光ディスク上のトラックとスポットとの関係を示した図である。３ビーム法のメインスポット２７、及び３０はトラック３２、３３の中央に位置し、サイドスポット２６、２９はトラック３３、３２の右に、サイドスポット２８、３１はトラック３３、３２の左に、それぞれ位置している。

【0007】情報の再生はメインスポット２７、３０によって行われる。フォーカス検出はメインスポット２７により、トラック検出はサイドスポット２６、２８により行われる。また、半導体レーザ４０の２個のレーザチップ４１、４２の間隔が１５０μmであり、光ディスク上のメインスポット２７、３０の間隔は光学系の横倍率が約１／５なので３０μmになる。メインスポット２７とサイドスポット２８との間隔は約１０μmである。そして、メインスポット２７、３０の存在により光ディスクの２つのトラックから同時に情報を再生することが可能である。

【0008】しかしながら、光ディスクの偏心によりトラックが横ずれを起こすと、メインスポットの一方はトラッキングサーボ制御により常にトラック中心に位置するが、他方のメインスポットはトラックずれを引き起こし再生信号が低下するという問題がある。

【0009】図５は光ディスクの偏心によるスポット位置ずれの説明図である。図５において、光ディスクに偏心がない時がトラック３２、３３であり、２つのメイン

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スポット３６、３７は各々トラック３２、３３（実線表示）の中心に位置している。しかし、光ディスクに偏心がある時にはトラック３４、３５（点線表示）にずれた位置にあり、一方のメインスポット３８はトラッキングサーボ制御により常にトラック３４の中心に位置するが、もう一方のメインスポット３９はトラック３５よりオフトラックした位置にある。このため、メインスポット３９により情報を再生すると信号が低下する。

【0010】この偏心の問題を解消するためにマルチビームのメインスポット相互の間隔を狭める方法が提案された。図６はメインスポット相互の間隔を狭めた従来のトラックとスポットとの配置図である。図６において、メインスポット２７、３０の間隔を狭め、３ビーム法のメインスポット２７、３０とサイドスポット２６、２８、２９、３１との間隔よりもマルチビームのメインスポット２７、３０相互の間隔を狭める方法が考えられる。図の例では、メインスポット２７とサイドスポット２６、２８とが１つのレーザ光源からの光であり、メインスポット３０とサイドスポット２９、３１とが他方のレーザ光源からの光である。メインスポット２７、３０の相互間隔は光ディスク１０の偏心による再生信号の低下が十分無視できる５μmに設定されている。

【0011】図７は図６のマルチビームの受光素子２１、２４、４６とスポット２６～３１との関係を示す図である。図において、非点収差法によるフォーカス信号を検出するための４分割受光素子４６、３ビーム法によるトラック信号を検出するための２つの受光素子２１、２２が一枚の基盤上に配置されている。

【0012】しかしながら、スポットの相互間隔が狭いため受光素子２１、２２上に２つのレーザチップ４１、４２を光源とするサイドスポット（２６と２９及び２８と３１）が照射されているため、フォーカス信号、トラック信号、再生信号が正確に検出できない問題が生じる。さらに、半導体レーザ４０に２個のレーザチップ４１、４２を搭載して２本のビームを発生させる方法はコストが高いという問題がある。そこで、一つの半導体レーザーと複屈折材料からなるくさび部材からマルチビームを生成し、偏光ビームスプリッタによりマルチビームを分離して受光素子に入射させることにより前述のレーザチップの問題を解決する方法が提案されている。

【0013】図８はくさび部材を使った従来のマルチビーム光ピックアップの構成図である。図８において、半導体レーザ４０から一本のレーザビームが発光している。このビームはコリメートレンズ２により平行光となり、グレーティング３により３本のビーム４に変換され、複屈折くさび部材５により常光線７（点線表示）と異常光線６（実線表示）に分離され合計６本のビームになる。

【0014】複屈折くさび部材５の材質には水晶が使用される。その水晶の波長７８０ｎｍの常光線７に対する

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屈折率は１．５３８７３８４、異常光線６に対する屈折率は１．５４７６６５８である。半導体レーザ４０からビームの偏光面を４５度回転させて複屈折くさび部材５に入射させると、複屈折くさび部材５の中でレーザ光は常光線７と異常光線６とに分かれて進行し、常光線７に対する屈折率と異常光線６とに対する屈折率が異なるため、複屈折くさび部材５から出射する際に２つの光線に分離されて異なる方向に出射することになる。例えば、くさびの頂角を１０度に設定すると分離された２つのビームのなす角度は０．０９０度になり、対物レンズ９の焦点距離を３ｍｍとすると２つのスポットの間隔は４．７μｍになる。このスポット間隔であれば、図６に示したように、光ディスク１０の偏心による再生信号の低下を十分無視する事ができる。

【0015】複屈折くさび部材５から２つの光線に分離され合計６本のビームとして出射した後、ハーフミラー８で全反射し対物レンズ９で集光されて光ディスク１０のスポットに焦点を結ぶ。

【0016】光ディスク１０からの反射光は、再び対物レンズ９を通りハーフミラー８を透過し、検出レンズ１１を通り、偏光ビームスプリッタ１２により、その入射光線の偏光面に応じて常光線７は反射され異常光線６は透過し受光素子１３に入射する。フォーカス検出は常光線１５と異常光線１４とのスポットサイズ法により行われ、トラック検出は公知の３ビーム法により行われる。

【0017】前述の図６において、３ビーム法のメインスポット２７、及び３０はトラック３２、３３の中央に位置し、サイドスポット２６、２９はトラックの右に、サイドスポット２８、３１はトラックの左に位置している。情報の再生はメインスポット２７、３０によって行われる。フォーカス検出はメインスポット２７により、トラック検出はサイドスポット２６、２８により行われる。

【0018】図９は受光素子１３上のスポットの配置を示した図である。異常光線１４を検出する受光素子は２０、２１、２２であり、常光線１５を検出する受光素子は２３、２４、２５である。受光素子２０と受光素子２３はそれぞれ３分割され、２０－Ａ，２０－Ｂ、２０－Ｃ、及び２３－Ａ，２３－Ｂ、２３－Ｃより構成される。メインスポット２７、３０の各々の集光点は受光素子１３の前後にあるため、フォーカス信号を

｛（２０－Ａ）＋（２０－Ｃ）－（２０－Ｂ）｝－
｛（２３－Ａ）＋（２３－Ｃ）－（２３－Ｂ）｝

より得ることができる。

【0019】またトラック信号は、２１－２２により得られる。

【0020】

【発明が解決しようとする課題】しかしながら、以上に説明した各従来の方法は、半導体レーザの光をコリメートレンズにより平行光に変換してから対物レンズに入射

させる無限系である。そのため検出光学系にも集光レンズが必要になり、光ピックアップが大型化ししかもコストアップになるという問題がある。

【００２１】さらに、半導体レーザに２個のレーザチップを搭載し２本のビームを発生させる方法はコストが高くなるという問題がある。

【００２２】また、従来の光ピックアップは半導体レーザや光学部品やセンサーが別々に配置されているため光ピックアップが大型化するという問題がある。

【００２３】以上のように、有限系の検出光学系を用い、小型で低コストなマルチビーム光ピックアップが要求されている。

【００２４】本発明は上記従来の問題点を解決するもので、１つの発光点を有する半導体レーザから複数のビームを生成し、複数のトラックを同時に再生することのできる小型で低コストなマルチビーム光ピックアップを提供することを目的とする。

【００２５】

【課題を解決するための手段】本発明の光ピックアップは、発光点が１つの半導体レーザと、くさび状の複屈折部材を互いに逆向きに接合した平行平板くさび部材と、複数の平行平板を一体に成型したラミレートプリズム部材と、受光素子とを一つのパッケージに形成して構成したものである。

【００２６】以上の構成により、半導体レーザから受光素子までを一体に組み込むことができるので、小型で低コストのマルチビーム光ピックアップが得られる。

【００２７】

【発明の実施の形態】本発明の請求項１に記載の発明は、１つの発光点を有するレーザ光源と、くさび状の複屈折部材を互いに逆向きに接合した平行平板くさび部材と、複数の平行平板を一体に成型し、その接合面の一部にグレーティングと、その接合面の他の一部に偏光ビームスプリッタとを有するラミレートプリズム部材と、複数の受光素子とを有し、レーザ光源の１本のビームを平行平板くさび部材により２本のビームに分割し、さらにグレーティングにより２本のビームをそれぞれ３分割し合計６本のビームとしてラミネートプリズム部材より出射させ、被検出面から反射した入射光をその偏光面に応じて偏光ビームスプリッタにより３本ずつ２つのグループに分離して受光素子により受光することとしたものであり、半導体レーザから受光素子までを一体に組み込むことができるので、小型で低コストのマルチビーム光ピックアップを提供することができる。

【００２８】以下、本発明の実施の形態について、図面を用いて説明する。

（実施の形態１）図１は本発明における光ピックアップの構造を示す図である。図において、半導体レーザ７０は保持部材７１上にマウントされ、半導体レーザ７０からのレーザビーム７３はくさび状の複屈折部材を互いに逆向きに接合した平行平板くさび部材７２により常光線８７と異常光線８６との２本のビームに分割される。

【００２９】ここで、平行平板くさび部材７２の材質には水晶が使用される。波長７８０ｎｍのレーザ光の常光線８７に対するその水晶の屈折率は１．５３８７３８４、異常光線８６に対するその水晶の屈折率は１．５４７６６５８である。また、平行平板くさび部材７２のうち第１の平行平板くさび部材７２ａの結晶配向に基づく光学軸は紙面と垂直方向に、第２の平行平板くさび部材７２ｂの結晶配向に基づく光学軸は紙面の上下方向にそれぞれ形成されている。

【００３０】今、半導体レーザ７０から出射するビームの偏光面を紙面の垂直方向から上下方向に向かって４５度回転させて平行平板くさび部材７２に入射させると、平行平板くさび部材７２の中でレーザ光は常光線８７と異常光線８６とに分離して進行する。さらに光学軸の相違により、常光線８７に対する屈折率と異常光線８６とに対する屈折率が異なるため、第１の平行平板くさび部材７２ａから出射する時と、第２の平行平板くさび部材７２ｂから出射する時とに２つの光線に屈折して分離し、異なる方向に出射することになる。例えば、くさびの頂角を５度に設定すると分離された２つのビームのなす角度は０．０９０度になり、対物レンズ８４の焦点距離を３ｍｍとすると２つのスポットの間隔は４．７μｍになる。このスポット間隔であれば、図６に示したように、光ディスク８５の偏心による再生信号の低下を十分無視する事ができる。

【００３１】分割された２本のビームはそれぞれ実線で示した異常光線８６と常光線８７としてラミネートプリズム７４に入射する。このラミネートプリズム７４は複数の平行平板７５、７６、７７、７８が接合された構造であって、その接合面の一部に光学的なコーティングがなされている。

【００３２】入射した２本のビームは、先ず、全反射コーティング７９により反射し、次にグレーティング８０で再び反射したとき、グレーティング８０によりさらに３本のビームに分かれて合計６本のビームになる。さらに、各ビームはビームスプリッタコーティング８１によりその一部が反射してラミネートプリズム７４を出射し、対物レンズ８４により集光され光ディスク８５に読み取りスポットを形成する。

【００３３】光ディスク８５のスポットからの反射光は、対物レンズ８４により再び集光されてラミネートプリズム７４に入射する。入射光はビームスプリッタコーティング８１を透過し、偏光ビームスプリッタ８２に達する。偏光ビームスプリッタ８２では入射光の有するその偏光面の相違（即ち、平行平板くさび部材７２により２本のビームに分割された時の偏光面）により、異常光線８６は偏光ビームスプリッタ８２を透過し基盤８９の受光素子９３～９５に入射する。他方、常光線８７は偏光ビームスプリッタ８２を反射し全反射コーティング７９により再び反射して基盤８８の受光素子９０～９２に入射する。

【００３４】トラック検出は公知の３ビーム法により、フォーカス検出は公知のスポットサイズ法により行われる。図２は本発明における受光素子の配置図である。常光線８７を受光する基盤８８の受光素子９０～９２には３ビーム法のサイドスポットを受光する受光素子９０、９２およびスポットサイズ法のメインスポットを受光する３分割受光素子９１がある。同様に、異常光線８６を受光する基盤８９の受光素子９３～９５には３ビーム法のサイドスポットを受光する受光素子９３、９５およびスポットサイズ法のメインスポットを受光する３分割受光素子９４がある。フォーカス信号は

｛９１Ｂ－（９１Ａ＋９１Ｃ）｝－｛９４Ｂ－（９４Ａ＋９４Ｃ）｝

より生成される。

【００３５】以上に詳細に説明したように、本発明によれば、単発光点の半導体レーザ７０を用いて、くさび状の複屈折部材を互いに逆向きに接合した平行平板くさび部材７２により２本のビームを生成し、このマルチビームをラミネートプリズム７４を介して対物レンズ８４に入射させて、２本のビームに基づく合計６本のビームによりビームスポットを光ディスク上に形成するので、単発光点の半導体レーザ７０により同時に２トラックをアクセスすることができる。

【００３６】さらに、ラミネートプリズム７４と複屈折部材を用いた平行平板くさび部材７２とが半導体レーザ７０と対物レンズ８４との光路中にあるため、対物レンズ８４はこれらの各部材の厚みにより発生する球面収差を補正するように設計することにより、ほぼ無収差の光学系を得ることが可能になる。

【００３７】また、偏光ビームスプリッタ８２により異常光線８６と常光線８７とを完全に分離して６個の各々の受光素子９０～９５に光を入射することが可能になる。さらに、本発明によれば、半導体レーザ７０から平行平板くさび部材７２、ラミネートプリズム７４、および基盤８８、８９までを光ピックアップに一体に組み込むことが可能になり、マルチビーム光ピックアップが大幅に小型化される。

【００３８】

【発明の効果】以上の様に本発明によれば、発光点が一つの半導体レーザを用いて、くさび状の複屈折部材を互いに逆向きに接合した平行平板くさび部材により２本のビームを生成し、このマルチビームをラミネートプリズムを介して対物レンズに入射させて、２つのスポットを光ディスク上に形成する。

【００３９】従って、単発光点レーザを使用して、同時に２本のトラックをアクセスすることができるので、先ず、ディスクの回転速度を増加することなく２倍のデータ点送料を実現することができ、省エネルギーと小型化とに効果的である。

【００４０】また、従来の無限系の技術ではコリメートレンズと検出レンズ（集光レンズ）とを必要としたが、本発明によれば有限系の技術によりこれらのレンズが不要となるのに加え、半導体レーザから平行平板くさび部材、ラミネートプリズム、および受光素子までを光ピックアップに一体に組み込むことが可能になり、マルチビーム光ピックアップが大幅な小型化とコストダウンが実現される。

【００４１】以上により、低コストでかつ小型化されたマルチビーム光ピックアップを提供することができる。

【図面の簡単な説明】

【図１】本発明における光ピックアップの構造を示す図

【図２】本発明における受光素子の配置図

【図３】従来のマルチビーム光ピックアップの構成図

【図４】光ディスク上のトラックとスポットとの関係を示した図

【図５】光ディスクの偏心によるスポット位置ずれの説明図

【図６】メインスポット相互の間隔を狭めた従来のトラックとスポットの配置図

【図７】図６のマルチビームの受光素子とスポットとの関係を示す図

【図８】くさび部材を使った従来のマルチビーム光ピックアップの構成図

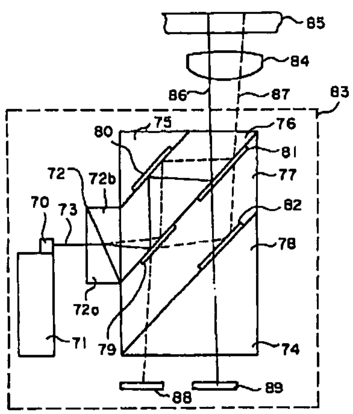
【図９】受光素子上のスポットの配置を示した図

【符号の説明】

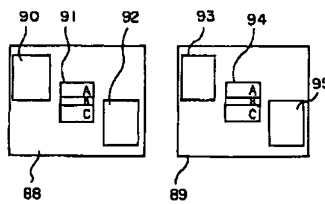
２　コリメートレンズ
３　グレーティング
４　３本のビーム
５　複屈折くさび部材
６、１４、８６　異常光線
７、１５、８７　常光線
８　ハーフミラー
９、８４　対物レンズ
１０、８５　光ディスク
１１　検出レンズ
１２、８２　偏光ビームスプリッタ
１３、２０、２１、２２、２３、２４、２５、４５、９０、９２、９３、９５受光素子
２７、３０、３６、３７、３８、３９　メインスポット
２６、２８、２９、３１　サイドスポット
３２、３３、３４、３５　トラック
４０、７０　半導体レーザ
４１、４２　レーザチップ
４３　検出レンズ
４４　シリンドリカルレンズ
４６　４分割受光素子
７１　保持部材

７２　平行平板くさび部材
７２ａ　第１の平行平板くさび部材
７２ｂ　第２の平行平板くさび部材
７３　レーザビーム
７４　ラミネートプリズム
７５、７６、７７、７８　平行平板
７９　全反射コーティング
８０　グレーティング
８１　ビームスプリッタコーティング
８８、８９　基盤
９１、９４　３分割受光素子

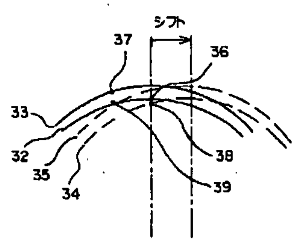
【図１】



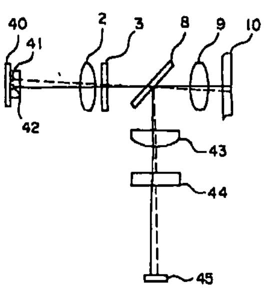
【図２】



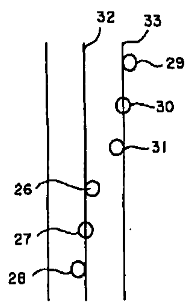
【図５】



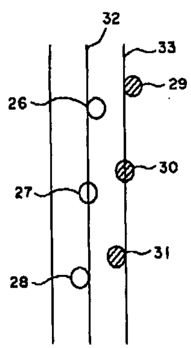
【図３】



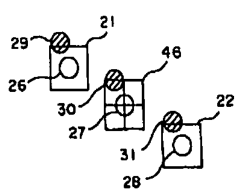
【図４】



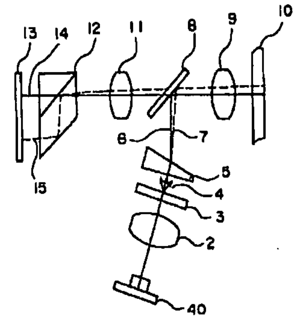
【図６】



【図７】



【図８】



【図９】